AD-A268 585

(2)

NSWCDD/TR-93/223

2010 COMBAT SYSTEMS VISION AND ACQUISITION FRAMEWORK

BY BERNARD G. DUREN JAMES R. POLLARD
COMBAT SYSTEMS DEPARTMENT

MAY 1993

Approved for public release; distribution is unlimited.

NAVAL SURFACE WARFARE CENTER
DAHLGREN DIVISION
Dahlgren, Virginia 22448-5000

NSWCDD/TR-93/223

2010 COMBAT SYSTEMS VISION AND ACQUISITION FRAMEWORK

BY BERNARD G. DUREN JAMES R. POLLARD
COMBAT SYSTEMS DEPARTMENT

MAY 1993

Approved for public release; distribution is unlimited.

NAVAL SURFACE WARFARE CENTER
DAHLGREN DIVISION
Dahlgren, Virginia 22448-5000

FOREWORD

Today the defense community faces a time of change and uncertainty. Changing world political and military conditions have caused the United States to adopt a new national security strategy and created a measure of change and uncertainty in basic missions and roles of the U.S. Navy. At the same time, many believe we are entering an era of fundamental and rapid change in warfighting systems and methods.

Since the 1950's, development of surface ship combat systems has followed a bottom-up design approach. The basic idea has been to divide component development activities among a loosely coordinated array of program offices. Each program office will build, test, and produce components that work (as stand-alone systems). While this approach yields weapon systems that work, it has so far prevented treating the warship itself as an integrated warfighting system, all parts of which must work in unison to carry out assigned mission tasks. The qualities of firepower, stealth, interoperability, and affordability required for effective service in future warfare environments make a top-down, integrated design process imperative.

Thus, new ways of doing business must now be considered. What the approach should be and how it can be implemented are vital questions for the Navy community. This report is the result of continuing efforts to foster a disciplined and systematic approach to top-down design of upgrade and new construction options for surface combatants of the 21st century.

Approved by:

Leaton M. Williams, III

LEATON M. WILLIAMS III
Head
Combat Systems Department

ABSTRACT

For an enterprise with lofty goals, plans must be formulated around a vision expressing its ultimate purpose and strategy. Such a vision brings the main factors governing conduct of the enterprise into focus and helps mobilize available resources to achieve success. This report presents a conceptual framework for design of surface combatants with increased ability to accommodate both new technologies and new maritime strategies. This framework includes a reference model or functional architecture for combat systems.

The report also considers implications of the framework for management of surface ship combat system development activities. Hence, it continues and expands on related work presented by NSWCDD Technical Reports 90-121, 91-607, 91-795, and 92-141, and NSWCDD Miscellaneous Publication MP-92/647. Design for interoperability and the potential for dual use of combat system technology are topics raised here for the first time. The overall goal is to ensure that the U.S. Navy will continue to be armed and equipped with effective, affordable and usable warships sufficient to execute a chosen concept of operations against an adversary that is both capable and determined.

CONTENTS

ILLUSTRATIONS

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1993	Final/May 1993

4. TITLE AND SUBTITLE
2010 Combat Systems–Vision and Acquisition Framework

5. FUNDING NUMBERS

6. AUTHOR(S)
Bernard G. Duren James R. Pollard

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center (Code N04)
Dahlgren Division
Dahlgren, Virginia 22448-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NSWCDD/TR-93/223

9. SPONSORING/MONITORING AGENCY NAME(S) AND

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NSWCDD/TR-93/223

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

For an enterprise with lofty goals, plans must be formulated around a vision expressing its ultimate purpose and strategy. Such a vision brings the main factors governing conduct of the enterprise into focus and helps mobilize available resources to achieve success. This report presents a conceptual framework for design of surface combatants with increased ability to accommodate both new technologies and new maritime strategies. This framework includes a reference model or functional architecture for combat systems.

The report also considers implications of the framework for management of surface ship combat system development activities. Hence, it continues and expands on related work presented by NSWCDD Technical Reports 90-121, 91-607, 91-795, and 92-141, and NSWCDD Miscellaneous Publication MP-92/647. Design for interoperability and the potential for dual use of combat system technology are topics raised here for the first time. The overall goal is to ensure that the U.S. Navy will continue to be armed and equipped with effective, affordable and usable warships sufficient to execute a chosen concept of operations against an adversary that is both capable and determined.

14. SUBJECT TERMS
Functional Architecture
Architectural Strategy

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and its title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements.***

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	**PR**	- Project
G	- Grant	**TA**	- Task
PE	- Program Element	**WU**	- Work Unit Accession No.

BLOCK 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If Known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD	- See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE	- See authorities.
NASA	- See Handbook NHB 2200.2
NTIS	- Leave blank

Block 12b. Distribution Code.

DOD	- Leave blank.
DOE	- Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA	- Leave blank.
NTIS	- Leave blank.

Block 13. Abstract. Include a brief ***(Maximum 200 words)*** factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code ***(NTIS only)***

Block 17.-19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of this page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

DISTRIBUTION

DOD ACTIVITIES (CONUS)

		Copies
ATTN	N6	1
	N 8	1
	N 81C	1
	N 85	1
	N 86W	1
	N 87	1
	N 88	1
	N091	1
	N 863	1
	N 865	1
	N 091	1

CHIEF OF NAVAL OPERATIONS
DEPARTMENT OF THE NAVY
WASHINGTON DC 20350-5000

		Copies
ATTN	SPAWAR 00	1
	SPAWAR 005	1
	SPAWAR 09	1
	SPAWAR 10	1
	SPAWAR 30	1
	SPAWAR 30T	1
	SPAWAR 31	1
	SPAWAR 31F	1
	SPAWAR 314	1
	SPAWAR 315	1
	SPAWAR 317	1
	SPAWAR 32	1
	PD 40	1
	PD 50	1
	PD 60	1

COMMANDER
SPACE AND NAVAL WARFARE
SYSTEMS COMMAND
WASHINGTON DC 20363-5100

		Copies
ATTN	DASN SHIP PROGRAMS	1
	DIR FOR SURF COMBATANTS	1
	DIR FOR ANTI-AIR WARFARE	1
	DIR FOR NAVAL WARFARE	1

ASSISTANT SECRETARY
OF THE NAVY (RDA)
DEPARTMENT OF THE NAVY
WASHINGTON DC 20350-5101

OFFICE OF THE COMMANDANT (CMC)
HEADQUARTERS
US MARINE CORPS
WASHINGTON DC 20380-0001 — 1

ATTN ONR 100 — 1
OFFICE OF THE CHIEF OF
NAVAL RESEARCH
BALLSTON TOWERS
800 N QUINCY STREET
ARLINGTON VA 22217-5000

		Copies
ATTN	CODE 208	1
	CODE 21	1

COMMANDER
OFFICE OF NAVAL TECHNOLOGY
800 N QUINCY ST
ARLINGTON VA 22217-5000

ATTN NSWC 00 — 1
NAVAL SURFACE WARFARE CENTER
WASHINGTON DC 20362-5101

DISTRIBUTION (CONTINUED)

	Copies
COMMANDING OFFICER COASTAL SYSTEMS STATION DAHLGREN DIVISION PANAMA CITY FL 32407-5000	1
COMMANDING OFFICER NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION WARMINSTER PA 18974	1
COMMANDER NAVAL UNDERSEA WARFARE CENTER DIVISION NEWPORT RI 02841-5047	1
ATTN (R Lobb) CENTER FOR NAVAL ANALYSIS PO BOX 16268 ALEXANDRIA VA 22302	1
DEFENSE TECHNICAL INFO CENTER CAMERON STATION ARLINGTON VA 22304-6145	2

	Copies
ATTN PMS 300	1
PMS 312	1
PMS 400 (T Hardy)	1
PMS 400B	1
PMS 411	1
SEA 00	1
SEA 05	1
SEA 06	1
SEA 06A	1
SEA 06C	1
SEA 06D	1
SEA 06K	1
SEA 06R1 (B Tootle)	1
SEA 06U	1
SEA 06W (S Davezac)	1
SEA 50	1
SEA 61	1
SEA 91	1
SEA 93	1
SEA 300	1
SEA 312	1
SEA 400	1
SEA 411	1
SEA 441	1
COMMANDER NAVAL SEA SYSTEMS COMMAND WASHINGTON DC 20362-5101	

NON-DOD ACTIVITIES

ATTN MSTO ADVANCED RESEARCH PROJECTS AGENCY VIRGINIA SQUARE PLAZA 3701 N FAIRFAX DRIVE ARLINGTON VA 22217-5000	1
ATTN M. LANGSTON THE JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY JOHNS HOPKINS RD LAUREL MD 20723-6099	1

DISTRIBUTION (CONTINUED)

INTERNAL:

		Copies
A		1
A01W		1
A01D		1
A10		1
A20		1
A30		1
A40		1
B		1
B10		1
B20		1
B30		1
B35	(Cullen)	1
B40		1
B50		1
C		1
D		1
D2		1
D4	(Lacey)	1
E		1
E231		3
E232		2
E281	(Orendorf)	1
F		1
FOX		1
F10		1
F20		1
F30		1
F40		1
G		1
G10		1
G20		1
G21		1
G30		1
G304		1
G40		1
G60		1
G80		1
G90		1

		Copies
K		1
K10		1
K20		1
K30		1
K40		1
K50		1
L		1
L04		1
L10		1
N		1
N01		1
N02		1
N04	(Duren)	50
N05		1
N05	(Gaston)	2
N10		1
N20		1
N20	(Burrow)	1
N30		1
N40		1
N50		1
N60		1
N70		1
N74	(GIDEP)	1
N80		1

INTRODUCTION

With the advent of the nineties, the U.S. Navy faces a time of change and uncertainty. At the same time, many believe we are entering an era of fundamental change in warfighting systems and methods. This is reflected in evolving maritime strategies, which place more emphasis on joint operations conducted from the sea. It is also reflected in evolving developmental priorities, which tend to emphasize automation and compression of the detection-to-destruction cycle for offensive weapon systems.

Underpinning and driving these changes in warfighting systems and methods is an era of fundamental change in productive systems and methods. Reference 1 constructs a vision of this era, premised on evolution of tightly integrated loops connecting all of the key actors in a commercial transaction: customer, producer, distributor, and payment agency. Underpinning these loops will be a system of lean production that uses less of everything compared with the mass production systems of the past: half the human effort in the plant, half the space for manufacturing, half the investment in tools, and half the engineering hours to develop new products in half the time. Plants will be designed to gain efficiency levels bordering on perfection and to achieve endless product variety with continually declining costs, zero defects, and zero inventories. This could impact world economic alignments and divide world economies into two classes—fast and slow. Virtually every enterprise that depends on large, complex productive systems is exploring new ways of doing business to realize this vision. Firms will adopt competitive strategies designed to achieve the greatest span of control and profitability with the least complexity and smallest size. In this regard, architectural strategies, wherein the firm seeks to be the standard setter for its business domain while relying on external sources for the greatest possible fraction of its total system, offer much promise. In this way, the notion of a force multiplier, long familiar in a military context, transfers to industrial activity.

We expect some corresponding change in the Navy's basic strategy for drawing on the raw military and industrial strengths of the U.S. to build surface combatants. As background, recall that development of naval combat systems has followed a bottom-up approach to design and development since the 1950's. The basic concept is to divide component development activities among a loosely coordinated array of program offices. In this system, each program office will build a little, test a little, debug, and finally produce the needed components. The combat system is subsequently produced by a process of component assembly and post-assembly integration. This approach fails to exploit evolving strengths of the U.S. industrial base and makes it difficult to achieve desired levels of interoperability with

expeditionary, joint, and allied forces. Thus it seems clear that new ways of doing business must be considered. What the approach should be and how it can be implemented are vital questions for the Navy. The right approach will create new opportunities to strengthen the U.S. industrial base as well. The technologies needed for integration and control of advanced combat systems apply broadly to computer-integrated manufacturing as well and thus have significant potential for dual use.

From this starting point, NSWCDD has begun to explore a vision of the future in surface ship combat systems. The desired vision had to be based on something more penetrating than pounding on the table and shouting, "Of course we need systems thinking–any idiot knows that!" A clear and succinct understanding of why combat systems are designed as they are and what makes the designs valid will enable us to build systems that are better in all respects—more usable, affordable, and functional. What is needed is a strategy that will permit continuous improvement of naval combat systems so that new technologies and new maritime strategies can be accommodated in all phases of the life cycle.

The proposed approach includes two major elements:

- *Reference Model*—A reference model or vision architecture is provided as a conceptual framework for combat system engineering. It includes a vocabulary that permits sharing of ideas and accumulated knowledge throughout the surface warfare community. With such intellectual tools one can proceed to dissect a maritime strategy and identify its implications for how combat systems should be designed and built.

- *Prototyping*—First steps toward an architectural strategy for combat system development are provided. This work is grounded in part on laboratory experiments and demonstrations as well as system engineering principles. While theoretical efforts aid discovery and communication of technical results, empirical work is more likely to influence ongoing programs in a substantive way. Empirical efforts are thus being used to explore a prototyping approach to design and development of open and extensible combat systems.

The question of how to organize for development is considered next. To identify key points of architectural control, offering leverage for a broad family of applications and systems, the combat system is partitioned into three major subsystems. The reference model is then extended to emphasize interoperability concerns and conclusions are presented. Early results suggest that it is possible to evolve toward an open combat system architecture that potentially meets the needs of large-deck aircraft carriers and amphibious ship types as well as cruisers and destroyers.

VISION ARCHITECTURE

A reference model or functional architecture is a key component of the vision for combat systems of the 21st century. This differs from an implementation architecture, which considers the arrangement of people, equipment, and computer programs. Combat systems are viewed as plants for processing targets formed on a mix of warfighting processes or action paths intended to deal with a variety of target types. While weapon systems produce individual action paths, combat systems create value by providing for setup, coordination, and control of many action paths. In short, combat systems that process targets better than the enemy's help to win battles.

Action paths in combat systems are the counterpart to the customer-oriented transaction loops found in commercial enterprises. Since they are critical to mission performance, we chose to begin formulating the reference model at this level. Figure 1 gives a notional view of functional flows in a typical action path. The illustration is taken from antiair warfare but sense, control, and engage sequences are present in all weapon systems. That is, all engagements require

- Sensing to gather target and environmental information
- Control to prioritize and assign weapons to targets
- Engagement to deliver energy against the target

Defining action paths can require significant technical effort and is a fundamental task in weapon design. However, it is useful to represent the series of discrete operations used in processing targets by a string of interconnected sense, control, and engage modules. Modules are viewed as functional rather than physical entities. For example, the sensing function in an antisurface warfare action path could be supported by an acoustic sensor intended primarily for detecting and tracking submarines. With this convention for describing action paths, we can consider coordinating multiple weapon systems, warfare mission areas, and multiple ships or aircraft.

Figure 2 shows the reference model as a network of modules arranged in three layers. The first (bottom) layer consists of action paths shown by convention as strings of sense, control, and engage modules. The second (middle) layer provides for coordination of warfare mission area modules each formed by a set of action paths (grouped by target category), plus an appropriate set of coordination functions. However, action paths can be grouped in other ways with little effect on the conceptual framework. The third (top) layer establishes tactical objectives for warfare mission area modules and assigns resources for their accomplishment.

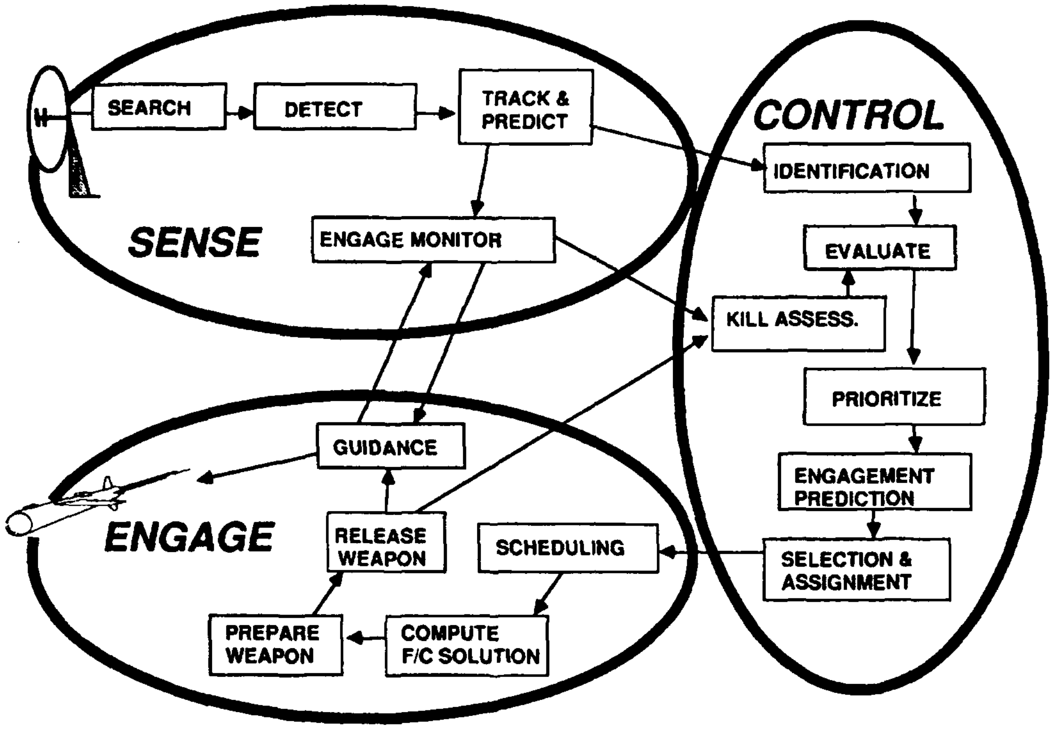

FIGURE 1. A WEAPON SYSTEM FUNCTIONAL DIAGRAM

Within each coordination layer, functional requirements are divided into the following components:

- Warfighting Coordination—Improves overall engagement performance by coordinating multiple action paths, especially to avoid waste and interference in their use.

- Information Coordination—Supports handling archival as well as tactical information, including communications with higher command authorities and cooperating tactical units. Information is inherently a shareable resource and offers many opportunities for improved combat system performance through cueing, fire coordination, or resource management. Information sharing implies internode communications, common data structures, and potentially a capability for dynamic management of information flows. Distribution can be achieved in broadcast or point-to-point modes horizontally within any level of the combat system hierarchy or vertically between levels.

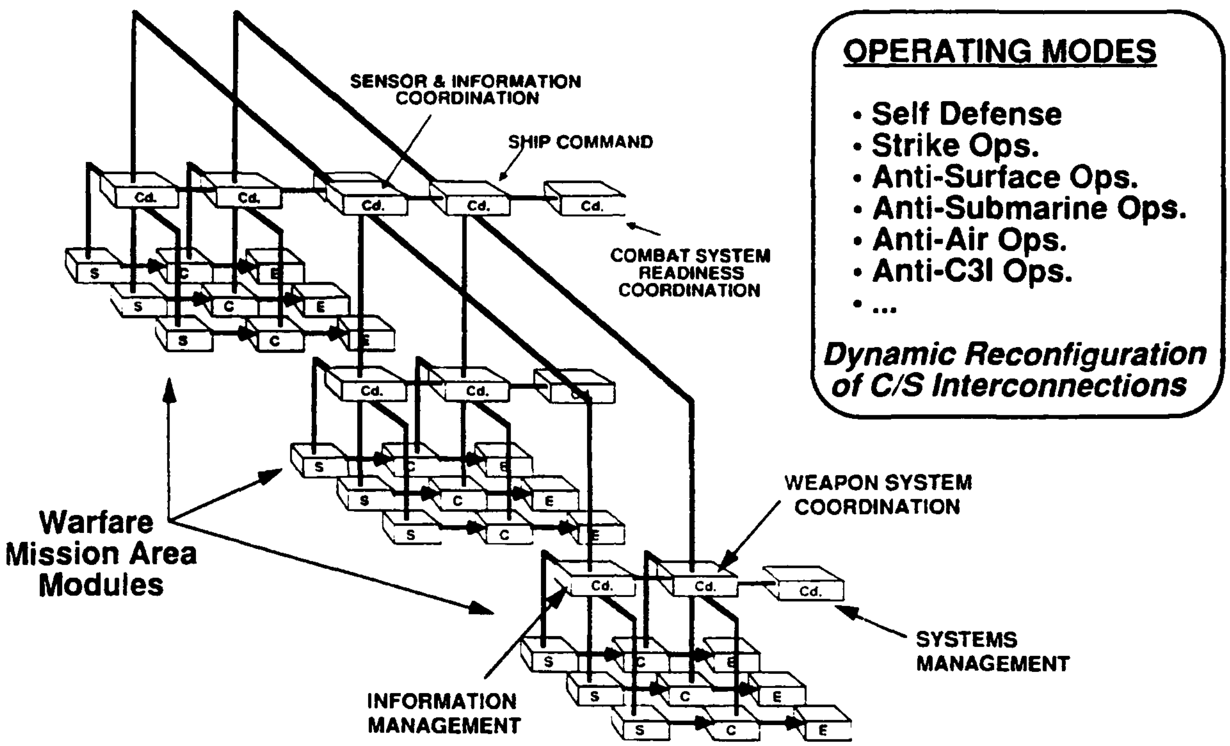

FIGURE 2. SINGLE SHIP WARFARE COORDINATION SYSTEM MANAGEMENT

- Resource Coordination—Includes key setup functions in the warfare mission areas (e.g., resource monitoring and allocation) that establishes which of the realizable action paths are available. Performance gains can also be sought by sharing components between action paths or weapon systems. The basic idea is to allow any-to-any interconnection of functional components. For example, the primary sensor of one weapon system might be used to support secondary or backup sensing functions of another weapon system. Examples can be constructed in such areas as flight operations, configuration control, and training. Full interoperability of combat system assets depends on commonality of resource access and global control structures. In particular, access to a higher authority may be necessary to resolve conflicting demands for use of a shared resource component or to budget use of limited resources.

Both information and resource coordination support are subordinate to the warfighting coordination function. These functions can be allocated to different individuals if necessary to ensure that the warfighting coordinator is not overburdened. Figure 2 shows the two levels of coordination for nominally three warfare mission areas with three action paths each.

The coordination layers introduce two additional path types to the architectural framework. The vertical paths that connect the commanding officer and tactical action officer to individual action paths are called command paths and form the command hierarchy of the combat system. Their role is to project command authority and protect its integrity throughout the combat system. The figure indicates that command paths support both readiness and warfighting coordination functions. A third path type forms the interconnecting structure for data flows within the combat system. This includes both vertical paths that connect the information coordination functions to sensing resources (including communications) and horizontal paths for sharing information between same-layer functional components. Overall, three fundamentally different control path types are shown in the figure: command, information, and action paths. This creates a potential for information and resource sharing that is essential to the integration and affordability properties of the combat system.

The structure of Figure 2 differs from physical architectures, which consider the arrangement of components such as equipment, people, and computer programs; and from implementation architectures, which consider the interconnections and information flows necessary to produce required system behavior. The reference model, a construct that is free of implementation-dictated allocations of functional requirements to objects or elements, may be common to many different implementations.

PROTOTYPING

While theoretical efforts aid discovering and communicating new ideas, experimental work is also necessary if significance of the lessons learned is to be widely appreciated. Simple demonstrations can draw wide attention and have substantial impact on existing programs, even in the near term. A series of tests have been conducted in the TOMAHAWK-AEGIS Display System facility (located at Dahlgren, Virginia) using the reference model as a guide for inr.ovation.

The first experiments which were designed as a test of its utility for identifying critical points in the structure of a combat system. With the introduction of Local Area Networks (LANs) and the Programmable Network Interface Units (PNIUs), it became possible to achieve new levels of interoperability between the TOMAHAWK and AEGIS weapon systems. Interoperability features demonstrated include using

common workstation hardware and computer programs, access to any operational mode (of either system) at any workstation by menu selection, and common access to tactical information at all workstations. It was also demonstrated that low-cost, highly capable commercial equipment and computer operating environments can perform embedded combat system control and display functions. Some of the features demonstrated suggest new ways to alleviate predicted shortfalls of time, memory, and input/output resources within the combat system. For example, AEGIS modules could be shifted to smart workstations, new functions could be implemented on the network using the considerable information available, and a PNIU could be used to network intercomputer channels and save computer slots.

Viewed in a broader context, these experiments argue for the utility of prototyping in development of advanced combat systems. The use of networking technology makes it easier to observe the dynamics of system behavior and creates new opportunities for easy, low-cost system improvement. When combined with networking technology, modularity in design makes the facility valuable as a testbed for assessing new ideas and emerging technologies.

Figure 3 indicates how future combat systems might be produced by an assembly process using this model as a design template. The bottom layer shown in the figure corresponds to the input side. It contains class models for every type of component needed to construct a combat system and a set of alternative point designs for each class. The middle layer, formed around the reference model, provides a template for selecting components to be used in particular designs. All information needed to define requirements and constraints for a specific combat system design must be accessible within this layer. The top layer represents the output side of the process and consists of point design solutions for one or more ship types.

Building the reference model into a testbed facility permits a prototyping approach to designing and developing combat systems. In particular, results suggest it is possible to progress toward an open combat system architecture in a conservative manner without any need to reinvent components that already work well. The value added by prototyping, as compared to conventional development, is to facilitate identification and validation of requirements through user involvement in an experimental mode. The result is a design and development process with the characteristics illustrated in Figure 4. Properly implemented, this approach could mean development time and cost savings of 30 to 50 percent through design flexibility and reusability of system components. A properly configured testbed facility could also pay off in transferring technology to computer-integrated manufacturing applications.

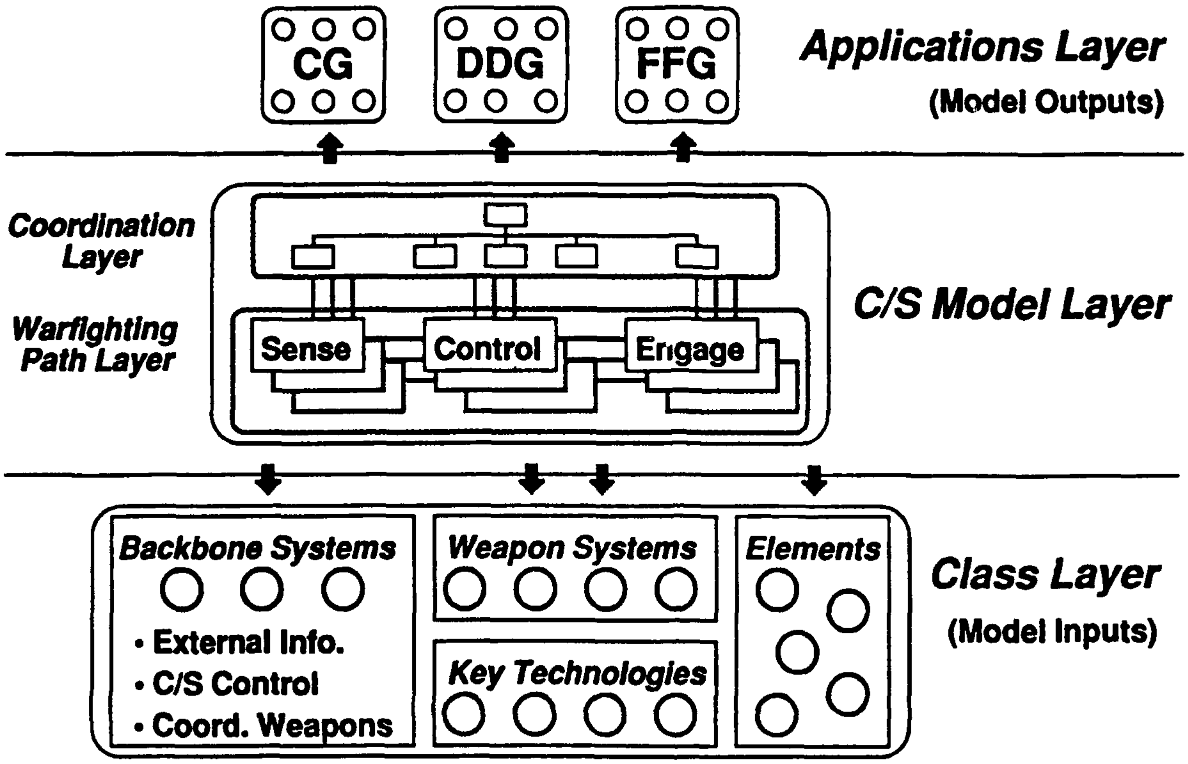

FIGURE 3. BUILDING OUTWARD FROM THE ARCHITECTURE MODEL

ORGANIZING FOR DEVELOPMENT

In most cases, system complexity increases rapidly with the number of components involved. We rely on the ancient divide-and-conquer strategy to manage this complexity. The idea is to decompose a large system into modules, each posing a simpler design problem. The strategy for partitioning a system into modules is based on consideration of domain clarity and distinctiveness, stability of domains and the interconnections between them, and minimal crossover (i.e., each subsystem should interact weakly with other subsystems). This last property is important because it permits a designer to change one part of a large system without creating a cascade of compensatory changes to other parts of the system. When the internal state of one

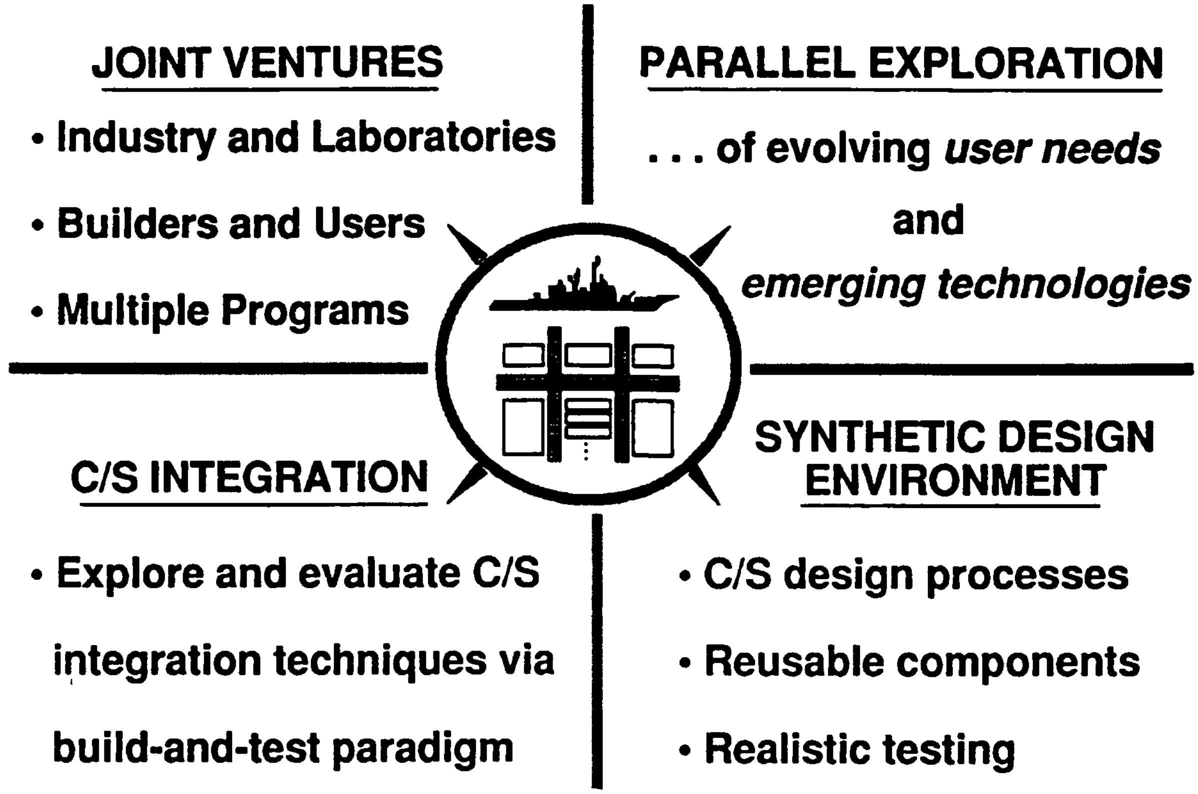

FIGURE 4. PROTOTYPING/TESTBED ACTIVITY

subsystem has strong influence on the internal state of other subsystems, the decomposition approach is more likely to complicate than to simplify the design.

Within the reference model, three classes of integrating structure occur. They correspond to the three different path types (command, information, and action paths) present in the model. In this section, we will first outline the three classes, then consider how they may be used to partition the problems of combat system design and engineering into three parts.

The first class of integrating structure is backbone control, which relates the combat system to the battle organization. This level of control enables the command team to provide loading and balance controls for the main operating tasks of the combat system. Space and time, information and processing, targets and ordnance, and energy and manpower are among the resources to be considered. The primary functions of backbone control are supervisory rather than direct control of target processing. As a backup or casualty mode, however, it is believed that command team workstations should have some capability for skip-echelon control of warfighting paths.

The second class of integrating structure provides for control of external information. This includes external communications, fusion of own ship with offboard information, and coordination of information flows throughout the combat system. The systems involved carry information vertically across combat system layers orthogonal to the horizontal structure of warfighting paths. Strike Warfare and Theater Air Defense (TAD) are examples of warfare tasks where these systems make important contributions. However, this structure does not include essential target processing and other information flows that take place within the lifelines of the ship (e.g., interior communications).

The third class provides for integrated control of multiple action paths within a warfare mission area. Action path clusters accomplish local control functions, including the coordination and direct control of individual action paths for target processing. The AEGIS Mk 7 Weapon System, for example, provides for shared use of resources across multiple simultaneous engagements. Separate control paths are provided for air intercept operations and self-defense assets (e.g., electronic countermeasures and minor caliber gun systems). Although quality of individual action paths is the primary concern at this level, multimission warships typically have two or more action-path clusters, so interoperability is also a key concern. Today, for example, we are attempting to develop advanced antiair self-defense systems that will integrate dissimilar action paths. Key technical problems include multisensor integration and the integration of hard-kill and soft-kill processes.

Continuing technological progress holds promise for all of the major subsystems identified above—control backbone, external information, and action-path clusters. In each area, major programs exist or are being created to work problems important to the Navy's future. For example, consider basic objectives for improvement of Navy command, control, and communications[2], which can be summarized as follows:

- Systems that are interoperable within services and between joint service, allied or coalition, and industrial or commercial structures

- Virtual multimedia networks responsive and reconfigurable by users

- A tactical picture available on a single screen in each command center that is consistent, unambiguous, readily comprehensible, and supports achieving a common perception of a tactical situation

- Essential elements of information maintained in databases that are consistent across command echelons and are automatically updated

- Decision-support tools configurable to meet situation-dependent needs

- Standardized fixed and user-portable multifunction, multimedia, intelligent information terminals

These objectives are closely aligned with those of the external information subsystem outlined above. Exceptions mainly have to do with command planning tasks that are not time-critical and can easily be supported by general-purpose information processing resources. Interfaces between the external information subsystem and other major subsystem types (backbone control and action path clusters) are the critical points of architectural control for achieving a combat system design that is fully responsive to the stated objectives.

The partitioning strategy influences how the Navy should be organized for design and development of future combat systems. The role of the development organization is to provide the information needed by producers to build practical and effective systems. In a sense, the key is how resources are allocated for translating requirements into an optimal set of products. A principle of system engineering for large, complex systems is that work units should be organized around the system structure. Use of any other organization implies that either a better subsystem partitioning exists or a potentially expensive mismatch of product and producer structures will be created.

The prototyping approach of the previous section, together with the partitioning strategy outlined above, implicitly define a supply chain for combat systems. The chain, as shown in Figure 5, contains four tiers: backbone tier, weapon system tier, elements and components tier, and enabling technologies. Each tier contains a set of class reference models, and each class in turn contains a set of particular systems or designs. A set of policy goals can be identified for each of the four tiers as follows.

- Backbone Tier—Emphasize open and interoperable backbone systems to form stable product lines in overall combat system control, external information, and action path clusters. The Navy gets maximum leverage in this area to form a flexible core for the fleet while retaining a measure of direction and control over how naval combat systems evolve.

- Weapon System Tier—The primary concern in developing weapon systems is quality of the warfighting paths; fundamental improvements in path quality are generated here. Key trends include movement toward resource sharing across weapon systems (e.g., sensor integration and multipurpose controllers) and movement toward multipurpose weapons for increased leverage through concentration of industrial base.

- Elements and Components Tier--Design elements and components for reusability (e.g., as multipurpose, shareable, and extensible resources).

- Enabling Technologies—The aim is to identify and focus on critical product lines and needs. The first goal should be to exploit emerging technology to form these tiers. Once the necessary open, reusable, and interoperable product lines have been established in each tier, the goal will be to move new technology quickly into backbone systems and selected weapon systems through evolutionary acquisition.

The backbone tier, a new feature in the supply chain, offers the greatest leverage for architectural control and should receive careful attention from Navy technical management agencies. Since the existing development organization is not optimized for this partitioning, it is appropriate to consider changes. This suggests a possible framework for acquisition of future combat systems based on the reference model. The optimum approach to technical management is the issue, rather than validity or utility of the reference model.

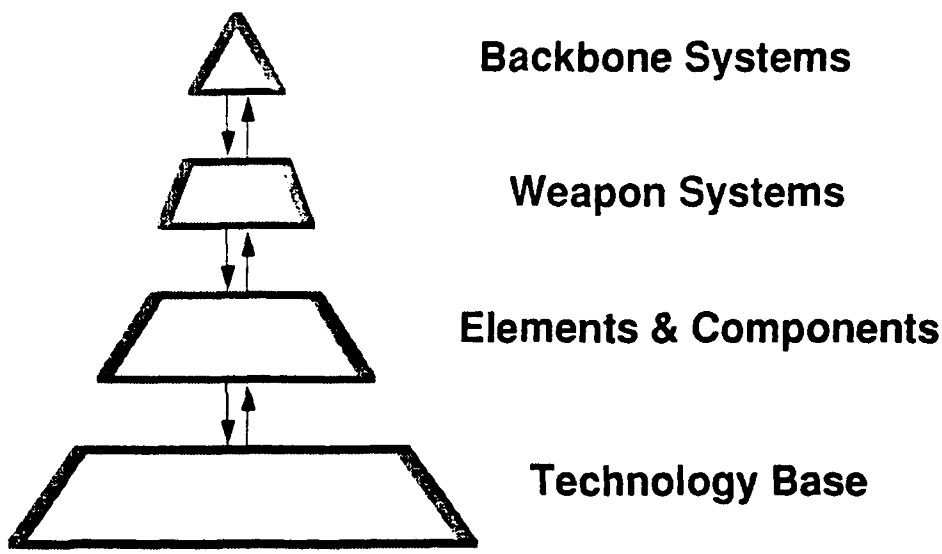

FIGURE 5. TIERED SUPPLY CHAIN

Some mechanism is also needed to coordinate architectures at the backbone system level. This mechanism should provide for consensus standards and top-level requirements, organization and development planning guidance, system-level oversight and control strategies, and policy coordination across service and DoD levels. Use of architectures and related standards, and efforts to capture and formalize design practices, allow the degree of information sharing necessary to practice modern system engineering methods in a naval/industrial team.

The root concern is the capacity of the Navy to build sustainable warfighting advantages from basic U.S. military and industrial strengths. Future combat systems must be more capable and affordable with the flexibility to incorporate new technologies and tailor in-service systems for evolving maritime strategies. However the world situation evolves, the Navy must be armed and equipped with effective

combat systems sufficient to execute a chosen concept of operations against a capable and determined adversary.

INTERACTIONS—A NEW PARADIGM

In essence, the architectural framework of Figure 2 is based on a sense-control-engage paradigm that has a long history of success in combat system engineering. This is a variation on the functional sense-control-act paradigm used for industrial process control and widely accepted in the manufacturing community. While many alternatives to this set of functions exist,[3] most offer only a change in wording; new insights are rarely achieved. Structural forms depend more on the partitioning principles that predominate in design than on the specific set of functions employed.[4] All the same, questions are being raised with increasing frequency about the necessity for continued reliance on the classical approach. The notion of interaction processes outlined below illustrates the potential for useful new paradigms to arise.

A combat system can be viewed as a collection of sequential processes together with means to control their use. In general, combat systems are designed to conduct two distinct types of interaction–engagement or cooperation–with external entities. Basic interactions involve a combat system plus one external entity and cannot be decomposed further. Composite interactions can be divided into several basic interactions combined sequentially, simultaneously, or recursively.

Engagement interactions are generally reactive in character, and targets are the external entities of interest. Reactive processes are characteristically designed to maintain some interaction with the environment, and termination occurs only if the system fails. Since there is no natural terminal state, the processes cannot be described by a simple relation specifying outputs as a function of inputs. They must instead be described in terms of ongoing behavior. Adequate descriptions usually involve treatment of some threat as a disturbance input. Response behavior may involve complex sequences of events, actions, conditions, and information flows, often with explicit timing constraints. A reactive process is said to be reflexive when human control is limited to supervisory functions, and direct control has been automated.

Cooperative interactions may be either transformational or reactive. A transformational process is one in which functionality can be described as a simple relation between initial state, inputs, and the outputs produced at some terminal state. Training, movement, and navigation processes are examples of this type. Maneuver in formation and air operations, which involve safety factors with a dynamic character, are examples of cooperative processes that are reactive in character. Cooperative interaction processes require signaling to communicate

status and purpose to the cooperating entity, session management to prioritize and set up a complex interaction sequence, and service delivery or receipt to complete the sequence. The external entities of interest in cooperative interactions may include units of U.S. naval forces, coalition partners, or neutrals. Modernization upgrades may be considered cooperative interactions in which the external entities are research and development (R&D) activities and the objective is insertion of new technology into the combat system.

Composite interactions mixing cooperative and engagement processes also occur. This involves a class of systems that carry information across multiple layers of warfighting coordination: that is, orthogonal to the horizontal structure of ordinary action paths. Strike and theater air defense are areas where such interactions are important. Mixed interactions can also occur within the lifelines when cooperative employment of multiple action paths within a single combat system or single warfare mission area is desired. Cooperative and mixed forms of interaction are driven by interoperability factors. Given today's emphasis on coalition warfare and joint operations in an era of regional conflict and littoral warfare, interoperability factors become very important. Technologies created to satisfy military needs for interoperability will also find many industrial applications as productive systems and methods continue to evolve.

Since the classical approach is limited to pure engagement interactions, looking at combat systems in terms of cooperative and mixed interactions invokes a new perspective. The new perspective involves signaling, session management, and service delivery categories of functionality as well as the classical sensing, control, and engagement categories. In essence, the new categories of functionality support creation of new action paths by any-to-any interconnection of sense, control, and engage components of own ship or some cooperating external entity (Figure 6). This approach holds promise for improved combat system flexibility, including the ability to adapt to changes in force structure, battle organization, employment doctrine, threat, operating environment, or technology. It can also be useful to explore alternative concepts for battle organization. As an example, it could be used to examine the feasibility of organizing a combat system around the mission categories outlined in the recent Navy white paper, ... *From the Sea*. Two of the four categories (command, control, and surveillance; power projection; battlespace dominance; and sustainment) are primarily cooperative in character.

There is a hidden assumption underlying the way we currently design and build combat systems—that information and control flows are relatively static. We expect data in these flow paths to change rapidly as the tactical situation changes, ordnance is expended, and new orders are received. We do not expect or provide for continuously redefining the way system tasks are viewed. The assignment of

resources to a given action path need not be a fixed characteristic of the design. Dynamic management of resource assignments will enhance the potential of future combat systems for cooperative interaction.

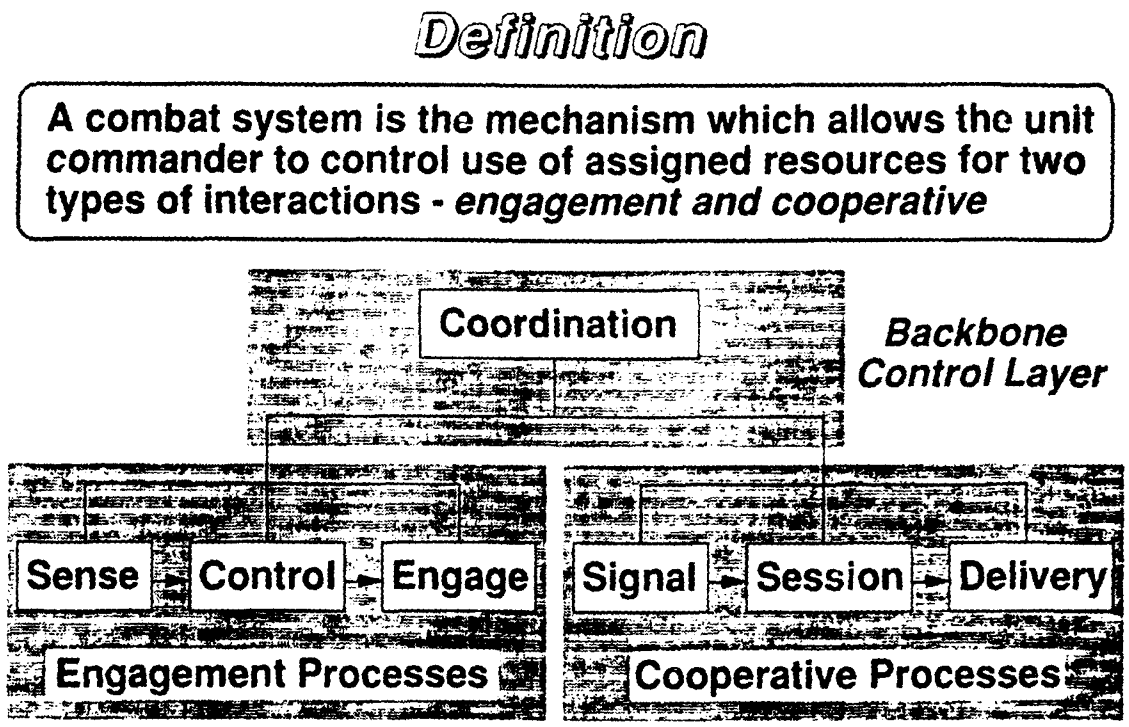

FIGURE 6. COMBAT SYSTEM FUNCTIONAL DECOMPOSITION

The design of sense, control, and engage components for any-to-any interconnection can support a virtually unlimited repertoire of action paths, and provide flexibility to create new operating modes tailored to specific operating tasks and roles. Effective use of a large repertoire enhances a commander's ability to dictate the terms of action and achieve the advantages of surprise in tactical operations. The existence of multiple data and control paths through the combat system also creates opportunities for increased survivability and growth potential compared to fixed path designs. Thus, future combat systems should be able to continuously redefine information and control flows by altering interconnection structures.

CONCLUSION

The desire for change in combat systems, no matter how urgent, must be reconciled with the realities of a large existing fleet. Today's fleet is both a valuable capital resource and a repository of our experience in building and operating naval forces. The processes of change in surface combatants are strongly evolutionary and are driven by military need as much as technology; radical change is both risky and rare. The dynamics of change are different at weapon system level where threat technology drives innovation and entire systems may be replaced when obsolete. Proper meshing of the two different change processes demands careful management. Given that tomorrow's Navy must evolve from where we are today, the pace of change is nevertheless accelerating. Shifting defense needs, technological progress, and prospective changes in acquisition strategy combine to make flexibility a key consideration in developing concepts for future combat systems.

We are trying to exploit this conceptual framework as an intellectual tool for identifying the critical products that provide architectural leverage for a broad family of applications and systems. These architecturally critical points represent, in effect, possible *force multipliers* for system design and development.

What are the critical products that provide architectural leverage for combat systems? We can focus narrowly on something like a PNIU or a LAN, and this is very appropriate for our (internal) technology management strategies. However, the answer in a broad context is the set of backbone structures given for system-wide control, external information, and action path clusters. As shown by Figure 5, the backbone tier represents the core of a Navy acquisition community structured to control the Navy's technical destiny while relying on external suppliers for the greatest possible fraction of its total system.

REFERENCES

1. Womack, James P., Daniel T. Jones, and Daniel Roos, *The Machine That Changed the World*, Rawson Associates, 1990.

2. *Copernicus Functional Description Document*, NCCOSC RDTE Division, draft, 5 April 1993.

3. Mayk, Israel and Izhak Rubin, "Paradigms for Understanding C^3, Anyone?," *Science of Command and Control: Coping with Uncertainty*, Johnson and Levis , Eds., AFCEA, 1988, pp. 48-61.

4. Johnson, T.L. and A.D. Baker, "Trends in Shop Floor Control: Modularity, Hierarchy, and Decentralization," in *Proceedings, 5th IEEE International Symposium on Intelligent Control*, Meystel, Herath and Gray, Eds., IEEE Computer Society Press, 1990, pp. 45-51.